ATTACHMENT 7

FTTS SOW

FTTS ACTD

Wheeled Vehicle Data Package for Dynamic Modeling & Simulation

(Provided for Informational Purposes Only)

ATTACHMENT 07 FTTS

WHEELED VEHICLE DATA PACKAGE FOR DYNAMIC MODELING AND SIMULATION

1.0 INTRODUCTION

This package describes the parametric data requirements for high resolution vehicle dynamic analysis using methodologies such as Dynamic Analysis and Design System (DADS). The nature of these methodologies is such that detailed vehicle data is necessary to formulate the models for the simulation to be performed. In order to facilitate the development of dynamic models of modern military tactical vehicle systems, an attempt has been made here to provide generic data sheets to define the system parameters necessary to conduct any desired simulations. These sheets include the minimal requirements necessary to conduct simulations. Special features or performance characteristics which are not covered by the data sheets need to be described and parameters provided in sufficient detail for high resolution dynamic simulations.

2.0 OBJECTIVES

The purpose of this package is to: 1) define in detail the parameters, drawings, and descriptions that are necessary to perform high resolution vehicle models using dynamic simulation methodologies and 2) provide standardized work sheets which will facilitate wheeled vehicle system description and model development.

3.0 CONCLUSIONS

It should be noted that the data defined in this package has a direct effect on the dynamic response of the vehicle. However the parameter values are generally quite difficult to determine. As the model can only be as accurate as the data provided, consideration should be given to collecting accurate and precise data to be used in the modeling process. When accurate data are used correctly in a vehicle dynamic simulation accurate results can be produced. From these results, decisions based on predicted vehicle performance can be made.

4.0 RECOMMENDATIONS

As the government deems it necessary, this package will be updated to add data requirements as modeling methodologies and simulation technologies advance.

5.0 DISCUSSION

In order to determine the dynamic response of wheeled vehicles, parametric data that describes the main subsystems of the vehicle must be known. The following data sheets are included to capture that data.

Models will be developed from each subsystem's parametric data and the models will be combined to create the vehicle model. The level of detail used to describe each subsystem and the accuracy of the parametric data will determine how well the model reflects the true system response.

5.1 Vehicle Mass and Inertia Properties

For the level of detail required for most analyses, it is sufficient to treat the vehicle sprung mass (chassis) as a single rigid body. However, if the first few mode shapes are known, provide the output from the finite element eigen value analysis from any FEA software package. This data can be incorporated into the dynamic model to provide additional accuracy. All spinning components of the wheel, such as the wheel hub and tire assembly, should be combined into one. If the axle is not composed of a single rigid body then its configuration should be depicted in additional drawings and the mass/inertia properties given for each major component. All center-of-gravity locations should be given relative to a point located on the ground below the center of the front axle or, if the vehicle does not have axles, at the centerpoint between wheel centers.

5.2 Wheeled Axle Data

For the most part, all of the data asked for on this sheet is self explanatory. The collection of this particular data gives us some background on what kind of tires will be used on the vehicle, how many wheels there are per axle and whether the axles are steered, powered, or braked. Operating load under the axle is important in helping us debug the model and would be useful at not only vehicle curb weight, but also at the various off-road and on-road loading conditions.

5.3 Tire Data (vertical and lateral force)

This section of data helps us in accurately characterizing the tire mechanical properties. It is important for us to get tire data for a range of tire inflation pressures that envelope the operating ranges that will be used during vehicle operation. This covers both on-road and off-road tire inflation pressures for a variety of gross vehicle weights. Tire vertical force data should reflect non-linear force/deflection up to the point of the tire bottoming out on the rim. Tire lateral force data should cover not only a range of tire inflation pressures but also a range of slip angles and tire vertical forces.

5.4 Suspension Characteristics and Data

Because of the wide variety of suspension systems in existence today, it is difficult to be explicit when specifying data requirements for a given vehicle suspension. It is important to emphasize that suspension systems significantly affect vehicle dynamic performance while negotiating terrain and obstacles, so they must be adequately modeled. Detailed drawings defining all suspension kinematics, joint locations, and attachment points of springs, shocks, and bump stops must be provided. All dimensions should be relative to a well-defined location on the vehicle such as a point on the ground located below the center of the front axle.

When providing suspension data for the vehicle it is important to cover the entire range of operation and include enough points to depict non-linearities in the suspension. This should include jounce and rebound characteristics as well. Tabulated data is required for force-deflection relationships, but including a plot of the data showing jounce, rebound and static equilibrium is desired. For independent suspensions, it should be stated whether the suspension force-deflection data is at the spring or the wheel, and if at the wheel, what the ratio is between the two.

5.5 Steering Data

Vehicle steering data will be required to set up an accurate model of the vehicle steering system. Linkage attachments points as well as steering parameters are required.

5.6 Powertrain Data

The inputs provided in the powertrain data sheets will allow for a more detailed and therefore more realistic model of the representative vehicle's propulsion. Two sections are attached for collecting the powertrain information, one is for a conventional powertrain arrangement, the other is for any advanced propulsion type. All information requested was done so to calculate tractive forces at the tire/ground interface. For advanced configurations, a control strategy and more detail may be necessary.

5.7 Supplemental Information

Additional data will be required to set up an accurate model of the vehicle system. This section covers data that would come in the form of engineering drawings. In particular, any drawings that depict the steering kinematics of the vehicle and supplemental drawings of the suspension showing damper and spring attachment points, axle attachment points, and bump stop locations. There should also be top level drawings of the vehicle including the system center-of-gravity location and overall vehicle dimensions.

[Narrative 5.7]

SUPPLEMENTAL INFORMATION

1) Provide dimensioned drawings showing position, geometry, connectivity and layout of the following:

a) Suspension springs and attachment points
b) Suspension dampers and attachment points
c) Torque rods, Panhard bar locations
d) Steering linkages
e) Vehicle hitch point
f) Vehicle center of gravity location with and without payload
g) Bump stop and rebound stop location
h) Top level drawings showing overall vehicle dimensions

Definition of Coordinate System:

The preferred coordinate system is fixed to the vehicle, and the x-axis points to the right. The y-axis points forward, and z -axis points upward as observed by the driver looking forward from the vehicle cab. The origin of the coordinate system is located at a point at the center of the truck front axle lying on a flat level surface at zero elevation so that a zero 'Z' value corresponds to zero elevation (on the ground).

** - If values are provided in a different method, please provide a clear definition of origin and orientation.*

2) If a hydraulic or air suspension is used, provide a schematic of the interconnectivity of the system, a control diagram with appropriate values for compressibility, bulk modulus, leadage, response and lag of all hydraulic and mechanical components.

3) VCW (Vehicle Curb Weight) defined as vehicle without crew, no ammo and/or payload, partially fueled. GVW (Gross Vehicle Weight) is defined as vehicle with crew, ammo and/or payload, and fully fueled.

4) Provide Finite Element Analysis Data for each body that such data exists
- Material Properties Used
- Description of Load Cases
- Type, Purpose, and Results of Analysis

[Narrative 5.1]

Vehicle Mass and Inertia Properties

Vehicle Component	Center of Gravity Location (in)(1)	Mass (lb-sec^2/in)	Pitch Moment of Inertia (lb-in-sec^2)	Roll Moment of Inertia (lb-in-sec^2)	Yaw Moment of Inertia (lb-in-sec^2)
Vehicle Total System Mass - VCW					
Vehicle Total System Mass - GVW					
Vehicle Sprung Mass (Chassis)					
Axle 1 (2)(3)					
Axle 2 (2)					
Axle 3 (2)					
Axle 4 (2)					
Left Spindle - Axle 1					
Left Spindle - Axle 2					
Left Spindle - Axle 3					
Left Spindle - Axle 4					
Left Wheel, Hub, Tire Assy. - Axle 1					
Left Wheel, Hub, Tire Assy. - Axle 2					
Left Wheel, Hub, Tire Assy. - Axle 3					
Left Wheel, Hub, Tire Assy. - Axle 4					
Additional Payloads, Kits, etc. *NOT* included with Chassis Sprung Mass					

(1) Please specify your origin and axis orientation that you use *(i.e. SAE (x-forward, z-down)* ; please be consistent

Axis Orientation: _____

Location of Origin: _____

(2) excluding spindle, wheel hub, and wheel

(3) If the axle is not composed of a single rigid body then indicate its configuration in drawings and give mass/inertia information for each major component.

[Narrative 5.2]

WHEELED AXLE DATA

Vehicle Name	**Axle 1**	**Axle 2**	**Axle 3**	**Axle 4**
Axle Load (lb)				
Steered (S) or Unsteered (U) Axle				
If Steered - Kingpin Inclination Angle (deg) or Steering Axle Inclination (deg)				
Wheel Camber Angle (deg)				
Wheel Caster Angle (deg)				
Wheel Toe-In Angle (deg)				
Powered (P) or Unpowered (U) Axle				
Braked (B) or Unbraked (U) Axle				
Number of Tires on Axle				
Single or Duals				
Tire Size & Designation				
Tire Undeflected Radius (in)				
Tire Highway Inflation Pressure (psi)				
Tire Cross-Country (Other) Inflation Pressure (psi) (1)				
Tire Deflected Radius Under Operating Load and Highway Pressure (in)				
Tire Deflected Radius Under Operating Load and Cross-Country Pressure (in) (1)				
Wheel Track Width (in)				
Longitudial Distance From Center of First Axle (in)				

(1) If vehicle includes Central Tire Inflation System (CTIS), include data for all CTIS settings.

[Narrative 5.3]

TIRE VERTICAL FORCE DATA

Tire Inflation Pressure[1]: _____ (lbs/in^2)

Tire Force-Deflection Data [2]

Deflection (in)	Force Loading (lb)	Force Unloading (lb)

Tire Force-Velocity Data

Velocity (in/s)	Force Loading (lb)	Force Unloading (lb)

[1] Please specify for all tire operating pressures. Make additional copies as needed.

[2] Tire data should reflect non linear force/deflection up to the point of the tire bottoming on the rim.

[Narrative 5.3]

TIRE LATERAL SLIP FORCE DATA

Tire Inflation Pressure[(1)]: _____ (lbs/in^2)

	Vertical Force (lb)	Vertical Force (lb)	Vertical Force (lb)	Vertical Force (lb)	Vertical Force (lb)
Slip Angle (deg)	Lateral Force (lb)	Lateral Force (lb)	Lateral Force (lb)	Lateral Force (lb)	Lateral Force (lb)

[(1)] Please specify for all tire operating pressures. Make additional copies as needed.

[Narrative 5.4]

SUSPENSION CHARACTERISTICS

	Axle 1	Axle 2	Axle 3	Axle 4
Static Load on Suspension With Payload (GVW) (lb)[1]				
Static Load on Suspension Without Payload (VCW) (lb)[1]				
Suspension Travel From Full Rebound to Full Jounce (in) measured at the wheel				
Wheel Travel to tip of Jounce-Bumpstop With Payload (in)				
Wheel Travel to tip of Jounce-Bumpstop Without Payload (in)				
Wheel Travel to tip of Rebound-Bumpstop With Payload (in)				
Wheel Travel to tip of Rebound-Bumpstop With Payload (in)				
Auxiliary Roll Stiffness (in-lb/deg)[2]				
Roll Center Height Above Axle (in)				
Rebound Bump Stop Stiffness (lb/inch of wheel travel)				
Jounce-Bump Stop Stiffness (lb/inch of wheel travel)				

[1] Please indicate whether this is per axle, per spring, and/or per side. This value is the axle load minus the weight of the unsprung axle weight.

[2] Roll stiffness due to torsion bars, torque rods, rubber bushings, frame stiffness, etc.

[Narrative 5.4]

SUSPENSION DATA

At Each Axle (Copy as necessary)

Suspension (spring + bump stops) Force-deflection Data (per side)		
Deflection (in)	Force Loading (lb)	Force Unloading (lb)
		(bottom out)
		(reach jounce stop)
		(reach rebound stop)
		(bottom out)

Shock Absorber Force-velocity Data (per damper)		
Velocity (in/s)	Force Loading (lb)	Force Unloading (lb)

1) Include sufficient data to adequately represent nonlinear spring characteristics.
2) Indicate whether this is per axle, per spring, and/or per side.
3) Indicate whether the damper data is for the damper alone or for the suspension assembly.
4) If damper will act as jounce or rebound limiter, include jounce and rebound stiffness in the spring curves.

5) For Semi-Active / Active Suspensions, provide rationale/logic/control scheme for determining suspension forces.

SUSPENSION COMPONENT ATTACHMENTS

[Narrative 5.4]

For the following, please provide detailed drawings and/or locations and orientations in 3-space

- Spring to Frame Attachment Points
- Shock Attachment Points
- MacPherson Strut Upper Bearing Attachment Points
- Control Arm Attachment Points (include Bushings)
- Spindle Attachment Points (include Ball Joints)
- Wheel Hub Attachment Points
- Road Arm / Trailing Arm Attachment Points
- Ball Joint Locations
- Bump Stop Locations
- Hitch Point

STEERING LINKAGE ATTACHMENTS

[Narrative 5.5]

Same as above, please provide detailed drawings and/or locations and orientations in 3-space

- Tie Rod Ends Attachment Points at Spindle
- Center/Drag Link Attachment Points
- Pitman / Idler Arm Attachment Points to Steering Gear and Drag Link
- Other

NOTE: Please provide any additional information that may have been overlooked and will be useful in constructing a model of this vehicle

[Narrative 5.5]

STEERING INFORMATION FOR WHEELED VEHICLES

STEERING SYSTEM

Steering Type[1]	
Steering Ratio	
Maximum Turning Angle of Wheel - RIGHT (deg)	
Maximum Turning Angle of Wheel - LEFT (deg)	

Pitman Arm Length (in)[2]	
Idler Arm Length (in)[2]	
Drag Link Length (in)[2]	
Tie Rod Length (in)[2]	

[1] Examples include Rack and Pinion, Recirculating Ball, Steer-by-wire, or other.

[2] Provide length measurements from the center of the ball studs.

[Narrative 5.6]

POWERTRAIN CHARACTERISTICS

NOTE: For advanced powertrain configurations (i.e. Hybrid electric, Fuel Cell, Hydraulic) please refer to 'Advanced Powertrain Characteristics' Sheet

Engine Manufacturer/Model	
Transmission Manufacturer/Model	

AERODYNAMICS

Vehicle Frontal Area (in^2)	
Frontal Drag Coefficient, Cd	
Side Drag Coefficient, Cd_{side}	

BRAKING DATA

Master Cylinder Area (in^2)	
Piston Frontal Area (in^2)	
Piston Rear Area (in^2)	
Prop Valve Cracking Pressure (lb/in^2)	
Brake Effective Frontal Radius (in)	
Brake Effective Rear Radius (in)	
Front Brake Factor	
Rear Brake Factor	

ENGINE DATA

Engine Inertia ($lb\text{-}in\text{-}sec^2$)	
Rotating Wheel Inertia ($lb\text{-}in\text{-}sec^2$)	
Maximum Engine Power (hp)	
Engine Speed at Max. Power (RPM)	
Idle Engine Speed (RPM)	

Engine Curves

- **Engine Performance Curve (RPM vs Gross Torque/HP)**
- **Engine Fuel Map (Fuel Consumption based on HP vs RPM)**
- **Engine RPM vs Accessory Torque Loss ($ft\text{-}lb_f$)**
- **Engine RPM vs Alternator Torque Loss (ft-lbf)**
- **Engine RPM vs Engine Fan Torque Loss ($ft\text{-}lb_f$)**
- **Percent Engine Power Loss vs Temperature (°F)**
- **Percent Engine Power Loss vs Altitude (ft)**

POWERTRAIN DATA

Final Drive Gear Ratio	
Final Drive Efficiency	

Transmission Gear Ratios (individual)	**Gear [1]**	**Ratio**	**Efficiency**
	1		
	2		
	3		
	4		
	5		
	6		
	7		
	8		
	9		
	10		
	Reverse		

[1] Please input values for the gear only if it exists, number of gears has been listed up to ten.

Transfer Case Gear Ratios (individual)	**Gear**	**Ratio**	**Efficiency**
	LOW		
	HIGH		

Gear Upshift/Downshift Map (Transmission/T-Case combined)						
	Transfer Case	**Transmission Gear**	**Gear Ratio**	**Efficiency**	**Upshift Spd (mph)**	**Downshift Spd (mph)**
	Low	1				
	Low	2				
	Low	3				
	Low	4				
	Low	5				

	Low	6				
	Low	7				
	Low	8				
	Low	9				
	Low	10				
	High	1				
	High	2				
	High	3				
	High	4				
	High	5				
	High	6				
	High	7				
	High	8				
	High	9				
	High	10				

Engine Speed-Torque Map	Engine Speed (RPM)	Net Engine Torque (lb-ft)
		0.0 (stall)

Torque Converter Characteristics	Input Speed (RPM)[2]	Speed Ratio	Torque Ratio	Capacity Factor[3]

[2] Also Indicate Speed at which lock up occurs

[3] Capacity Factor is the ratio of converter pump speed (RPM) divided by the square root of the pump torque (lb-ft)

[Narrative 5.6]

ADVANCED POWERTRAIN CHARACTERISTICS

- Please provide diagrams that will show the layout of any advanced powertarin components.
- Any additional information relating to vehicle propulsion should also be included.
- The control strategy for advanced components

Engine Manufacturer/Model (include fuel type)	
Electric Motor / Generator Manufacturer/Model	
Power Storage / Battery Type	
Transmission Manufacturer/Model	

AERODYNAMICS

Vehicle Frontal Area (in^2)	
Frontal Drag Coefficient, Cd	
Side Drag Coefficient, Cd_{side}	

BRAKING DATA

Master Cylinder Area (in^2)	
Piston Frontal Area (in^2)	
Piston Rear Area (in^2)	
Prop Valve Cracking Pressure (lb/in^2)	
Brake Effective Frontal Radius (in)	
Brake Effective Rear Radius (in)	
Front Brake Factor	
Rear Brake Factor	

POWER STORAGE / BATTERY PACK INFORMATION

Battery Output (volts)	
Rated Capacity (Amp-hrs)[1]	

[1] Please make note of any benefits provided due to regenerative braking

ENGINE DATA

Engine Inertia ($lb\text{-}in\text{-}sec^2$)	
Rotating Wheel Inertia ($lb\text{-}in\text{-}sec^2$)	
Maximum Engine Power (hp)	
Engine Speed at Max. Power (RPM)	
Idle Engine Speed (RPM)	

Engine Curves

- **Engine Performance Curve (RPM vs Gross Torque/HP)**
- **Engine Fuel Map (Fuel Consumption based on HP vs RPM)**
- **Engine RPM vs Accessory Torque Loss ($ft\text{-}lb_f$)**
- **Engine RPM vs Alternator Torque Loss (ft-lbf)**
- **Engine RPM vs Engine Fan Torque Loss ($ft\text{-}lb_f$)**
- **Percent Engine Power Loss vs Temperature (°F)**
- **Percent Engine Power Loss vs Altitude (ft)**

MOTOR DATA

Max. Power Output (hp)	
Max. Output Torque ($ft\text{-}lb_f$)	

Motor Curves

- **Power/Torque Characteristics vs RPM**
- **Voltage Draw**
- **Any Motor Losses**

HYBRID SYSTEM

- **Net System Performance Curve (RPM vs Gross Torque/HP)**

POWERTRAIN DATA

Final Drive Gear Ratio[2]	
Final Drive Efficiency	

[2] Please include relevant information if a constant variable transmission (CVT) is present.

Transmission Gear Ratios (individual)	Gear [3]	Ratio	Efficiency
	1		
	2		
	3		
	4		
	5		
	6		
	7		
	8		
	9		
	10		
	Reverse		

[3] Please input values for the gear only if it exists, number of gears has been listed for convenience up to ten.

Transfer Case Gear Ratios (individual)	Gear	Ratio	Efficiency
	LOW		
	HIGH		

Gear Upshift/Downshift Map (Transmission/T-Case combined)						
	Transfer Case	Transmission Gear	Gear Ratio	Efficiency	Upshift Spd (mph)	Downshift Spd (mph)
	Low	1				
	Low	2				
	Low	3				
	Low	4				
	Low	5				
	Low	6				
	Low	7				
	Low	8				
	Low	9				
	Low	10				
	High	1				
	High	2				
	High	3				
	High	4				
	High	5				
	High	6				
	High	7				
	High	8				
	High	9				
	High	10				

Engine Speed-Torque Map	Engine Speed (RPM)	Net Engine Torque (lb-ft)
		0.0 (stall)

Torque Converter Characteristics	Input Speed (RPM)[4]	Speed Ratio	Torque Ratio	Capacity Factor[5]

[4] Also Indicate Speed at which lock up occurs

[5] Capacity Factor is the ratio of converter pump speed (RPM) divided by the square root of the pump torque (lb-ft)

WHEELED VEHICLE CHARACTERISTICS[(1)]

	VCW	GVW
WEIGHTS (lb)		
Sprung		
Unsprung		
SYSTEM C.G. (in)		
Lateral		
Fore-aft		
Vertical		
SPRUNG MASS C.G. (in)		
Lateral		
Fore-aft		
Vertical		
SYSTEM MOMENTS OF INERTIA (lb-in-sec^2)		
Pitch		
Roll		
Yaw		
SPRUNG MASS MOMENTS OF INERTIA (lb-in-sec^2)		
Pitch		
Roll		
Yaw		
SPRUNG MASS NATURAL FREQUENCIES (cyc/sec)		
Bounce		
Pitch		
Roll		
Vehicle Vertical C.G. (in)		
Vehicle Track Width (in)		
Roll Stiffness (in-lb/deg)		
Front Suspension		
Rear Suspension		
Roll Center Height (in)		
DRIVER'S SEAT POSITION (in)		
Lateral		
Fore-aft		
Vertical		
DRIVER'S EYE POSITION (in)		
Lateral		
Fore-aft		
Vertical		
CARGO BED HEIGHT (in)		

(1) Values should be consistent with data provided in previous sheets.